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EPITAXIAL GARNETS AND HEXAGONAL FERRITES.(U)

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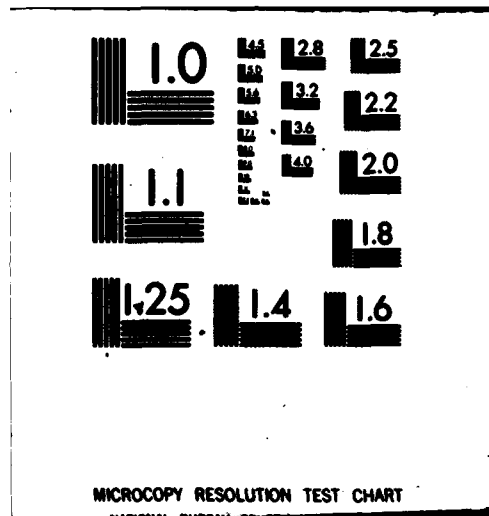
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The objective of this research is to develop new and improved epitaxial ferrite materials for use in microwave and millimeter-wave signal processing devices. The major emphasis has been on multiple layer epitaxial garnet structures for magnetostatic wave delay lines. Theoretical analysis was made for magnetostatic surface wave and magnetostatic forward volume wave propagation in structures containing two or three different magnetic garnet layers. Two-layer structures were prepared by liquid phase epitaxy using yttrium iron			

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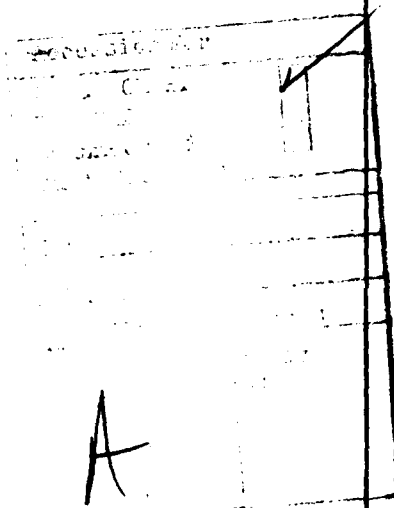
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garnet as a high magnetization layer and lanthanum-gallium substituted yttrium iron garnet as a lower magnetization layer. Measurements of magnetostatic wave propagation at frequencies in the 1 GHz to 6 GHz range were generally in good agreement with the theory. For magnetostatic surface waves, non-dispersive delays of approximately 200 MHz bandwidth at a center frequency of 3 GHz are obtainable. Delay time can be varied from about 50 nsec/cm to 120 nsec/cm by choice of the layer thickness and magnetization. For magnetostatic forward volume waves, it appears to be possible to obtain 1 GHz bandwidths in linearly dispersive delay lines operating at X-band. In addition to the garnet work, research on growth of single-crystal layers of lithium ferrite was performed. The liquid phase epitaxy method, which was developed on a previous contract, was modified to improve the crystallographic quality of lithium ferrite layers on zinc gallate spinel substrates. Microwave evaluation of the layers has not yet been completed.



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EPITAXIAL GARNETS AND HEXAGONAL FERRITES

AFOSR CONTRACT F49620-79-C-0048

Final Scientific Report

Howard L. Glass, Principal Investigator

February 28, 1980

I. OBJECTIVES

The overall objective of this research is to develop new and improved epitaxial ferrites which will be suitable for use in a variety of microwave and millimeter-wave devices. The specific tasks are defined in the work statement:

- a. Analyze and develop special layered garnet structures for propagating magnetic wave devices operating at frequencies between 1 GHz and 25 GHz.
- b. Investigate epitaxial hexagonal ferrites for use in devices operating at frequencies above 25 GHz.
- c. Furnish up to eight (8) liquid phase epitaxy yttrium iron garnet films to RADC/EEA for testing and evaluation.

These tasks represent a continuation of work done under the previous contract, F44620-75-C-0045. Task a. relates primarily to the use of magnetostatic waves in devices similar to surface acoustic wave (SAW) devices, but operating at higher frequencies. Task b. represents an exploration of the growth of other types of ferrites which have special capabilities beyond those of garnet-structure ferrites. Task c. is based on the achievements under the previous contract which led to the preparation of superior quality yttrium iron garnet (YIG).

II. ACCOMPLISHMENTS

- a. We performed theoretical analyses and experimental demonstrations of magnetostatic surface wave (MSSW) and magnetostatic forward volume wave (MSFVW) propagation in multiple layered structures. By manipulating the physical characteristics of the individual layers and the overall structure geometry, we were able to control the dispersion characteristics of delay lines based on propagation of these waves.

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For MSSW the analysis considered a four-layer structure in which the magnetization and thickness of each layer were selectable. The effect of finite transverse dimensions was included. Three basic configurations were analyzed in detail: two layers with different magnetization separated by a non-magnetic dielectric; two layers with different magnetization with no intervening layer; three layers with different magnetizations and no intervening layers. The dispersion for these three structures was calculated as a function of layer separation, thickness and magnetization. The major conclusion was that manipulation of these parameters can be used to vary the delay time, bandwidth and slope of the "non-dispersive" region of the delay vs. frequency curve. For example, at a center frequency of 3 GHz, the delay can be varied between 50 nsec/cm and 120 nsec/cm by proper selection of film thickness and magnetization. Also, the "non-dispersive" region can be made much flatter than in conventional single layer delay lines. A non-dispersive bandwidth of about 200 MHz at a center frequency of 2.5 GHz is obtainable.

Similar structures were analyzed for MSFVW propagation: There is an important difference between surface and volume wave propagation. In structures containing two layers with different magnetization, coupled MSFVW propagation occurs only when the low frequency cut-off of the high magnetization layer lies below the high frequency cut-off of the low magnetization layer. In this overlap region, the dispersion can be manipulated. In particular, the spacing between two magnetic layers can be adjusted to optimize the linearly dispersive delay characteristics. The results are similar to those obtained, by others, using a single magnetic layer with a ground plane separated from the layer by a thin dielectric spacer. Linear dispersion with 1 GHz bandwidths at X-band appears to be possible. The multiple layer approach offers the advantage of forming a monolithic structure during the epitaxial growth process.

To test the theoretical analyses and to demonstrate the propagation characteristics, multiple layer structures were prepared. Nominally pure YIG was grown for the high magnetization layers and La, Ga substituted YIG was grown for the low magnetization layers. To provide an intervening non-magnetic layer, the YIG layers were grown on opposite faces of the GGG substrates. Experiments on LPE growth of GGG to serve as thinner non-magnetic layers were carried out with some success. For MSSW, there was very good agreement between measured and calculated dispersion curves. For MSFVW, the agreement was generally good, but the measurements were hampered by transducers which were not optimized for the higher operating frequencies of volume wave measurements. A few samples showed poor agreement. These samples also exhibited complex FMR spectra, suggesting that the structures were more complex than just two uniform magnetic layers. This matter will be subject to further study under our new contract.

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Since layer uniformity is an important consideration, we cooperated with other investigators from our Research Center to develop X-ray methods to determine strain distributions in epitaxial layers. The technique has been applied to strains induced by ion-implantation of epitaxial garnets. We are adapting the method to study strain distributions at the layer-substrate interface.

b. With the concurrence of the technical monitor, most of the hexagonal ferrite effort was directed toward a resumption of research on epitaxial lithium ferrite. In the previous contract, we demonstrated the growth of lithium ferrite on gallate spinel substrates using the isothermal dipping method of liquid phase epitaxy (LPE). In that work, which has been published in Mat. Res. Bull. 13 (1978) 353-359, we encountered some difficulties because the LPE solution did not drain freely from the sample surfaces. In the present contract, we investigated modifications of the $\text{PbO-B}_2\text{O}_3$ LPE flux. Specifically, we increased the $\text{PbO:B}_2\text{O}_3$ mole ratio from a value of 1.95 to values in the range 16 to 29. This greatly improved the drainage and resulted in more uniform epitaxial layers having much smoother surfaces. In step with the increased $\text{PbO:B}_2\text{O}_3$ ratio, we found that it was necessary to increase the $\text{Fe}_2\text{O}_3:\text{Li}_2\text{CO}_3$ ratio from a value of 1.48 in the previous work to values in excess of 2.8. Failure to increase this ratio results in formation of lithium ferrate (LiFeO_2) instead of the desired lithium ferrite (LiFe_5O_8).

The lithium ferrite layers were grown on ZnGa_2O_4 substrates. The principal faces of the substrates were natural (111) facets or nominally (111) polished surfaces. A few substrates with nominally (100) polished surfaces were used also. The crystallographic quality of layers on (111) surfaces was generally good, though a terraced morphology was commonly found. X-ray double crystal diffraction peaks from areas a few millimeters in diameter were reasonably sharp. For the best samples, the peaks were about two minutes wide and were symmetric. This corresponds to uniform material with a strain of less than 6×10^{-4} . The strain appears to be due mainly to long range distortions in the substrates. Film-substrate misfit was undetectable. Microwave characterization of these samples has not been completed and will be continued under our new contract. Thus far, our ferromagnetic resonance measurements show that the spectra are cleaner and are more like good single crystal spectra than were the spectra of our previous materials.

c. In July, we delivered to RADC/EEA, a set of bar shaped LPE garnet samples with $31.5\mu\text{m}$ film thickness. We were informed that initial evaluation showed acceptably low insertion loss and that the material appeared to be satisfactory for the intended use.

III. PERSONNEL

H. L. Glass served as principal investigator and carried out much of the crystal growth and the crystallographic characterization. L. R. Adkins, who joined this research effort during the previous contract, was a major contributor and performed the FMR and microwave analyses. F. S. Stearns carried out many of the crystal growth experiments and some crystal processing. He grew most of the spinel substrate crystals and many of the YIG films. D. Medellin performed the necessary spinel substrate polishing.

IV. WRITTEN PUBLICATIONS

We are presently writing two papers on the garnet work:

1. L. R. Adkins and H. L. Glass, "The Propagation of Magnetostatic Surface Waves in Multiple Magnetic Layer Structures," to be submitted to Electronics Letters.
2. L. R. Adkins, J. H. W. Liaw and H. L. Glass, "The Propagation of Magnetostatic Forward Volume Waves in Multiple Magnetic Layer Structures," to be submitted to IEEE Transactions on Microwave Theory and Techniques.

In addition, upon completing the microwave characterization of our lithium ferrite samples, we expect to submit a paper to the Third International Conference on Ferrites for inclusion in the proceedings.

V. SCIENTIFIC INTERACTIONS

Work performed under this contract has been, or will be, reported in the following oral presentations:

1. H. L. Glass and V. S. Speriosu, "X-ray Double-Crystal Diffraction of Non-uniform Epitaxial Layers," Fourth Conference on Crystal Growth, American Association for Crystal Growth, Western Regional Section, May 1979, Stanford Sierra Camp, California.
2. H. L. Glass, "New Epitaxial Materials for the Electronics Industry," Advances in Mechanics and Materials Science Symposium, October 1979, Rutgers University, New Jersey.
3. H. L. Glass and V. S. Speriosu, "Tailoring Magnetic Properties in Epitaxial Ferrites," U.S.-France Seminar on Application of X-ray Topography to Materials Science, NSF-CNRS Seminar Series, March 1980, University of Paris, France.

4. H. L. Glass and F. S. Stearns, "LPE Growth of Ferrites from $PbO-B_2O_3$ Flux," Fifth Conference on Crystal Growth, American Association for Crystal Growth, Western Regional Section, May 1980, Stanford Sierra Camp, California.

We are planning to submit a paper on our lithium ferrite work to the Third International Conference on Ferrites to be held in September 1980.

Our interactions during the contract period included meetings and discussions with researchers from a variety of universities, companies and government laboratories. Visitors to our laboratory included our counterparts working on epitaxial microwave ferrites at Westinghouse, University of Texas and MIT. Government visitors included R. Colvin and M. Stiglitz of RADC and H. Lessoff of NRL. The principal investigator visited Fort Monmouth to brief Army scientific and technical personnel on the activities of the program. A meeting with the technical monitor was held at the INTERMAG Conference in New York.

As in the past, we have provided samples of our epitaxial ferrite materials to other investigators. During the contract period, samples were sent to Professors F. R. Morgenthaler of MIT, B. A. Auld of Stanford and E. Folke Bolinder of Chalmers University. In addition, we agreed to having the technical monitor make our samples available to the University of Texas. We received a University of Texas sample for FMR and X-ray analysis.

VI. INVENTIONS

Several discoveries and inventions have been reported to our company Patent Department. These are described separately in Abstracts of New Technology submitted to AFOSR. The company has not yet decided whether patent applications will be filed.

During the contract period, we cooperated with the Air Force's Hanscom Patent Prosecution Office in the filing of a patent application on a "Method for Controlling Resonance Frequency of Yttrium Iron Garnet Films."

A patent, "Epitaxial Growth of M-type Hexagonal Ferrite Films on Spinel Substrates and Composite," was issued for an invention made during the previous contract. The inventors are H. L. Glass, F. S. Stearns and D. M. Heinz.